Space Technology

Propulsion

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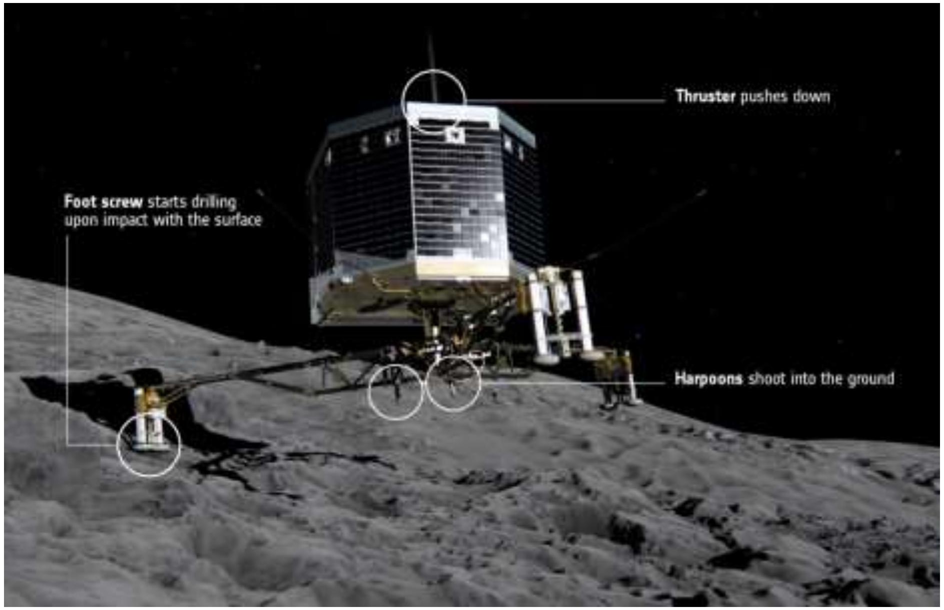
The task of propulsion

1. Place the spacecraft to its orbit
   - booster, main and upper stage engines
   - rocket engines thermal power between 3-30GW!!

2. As spacecraft subsystem: modify/correct the orbit
   - attitude control systems



Rocket propulsion

- Energy released->high pressure and temperature->nozzle

Tsiolkovsky rocket equation:

$$\Delta v = v_{exhaust} \ln \frac{m_{total}}{m_{final}}$$

Speed gain of stages:

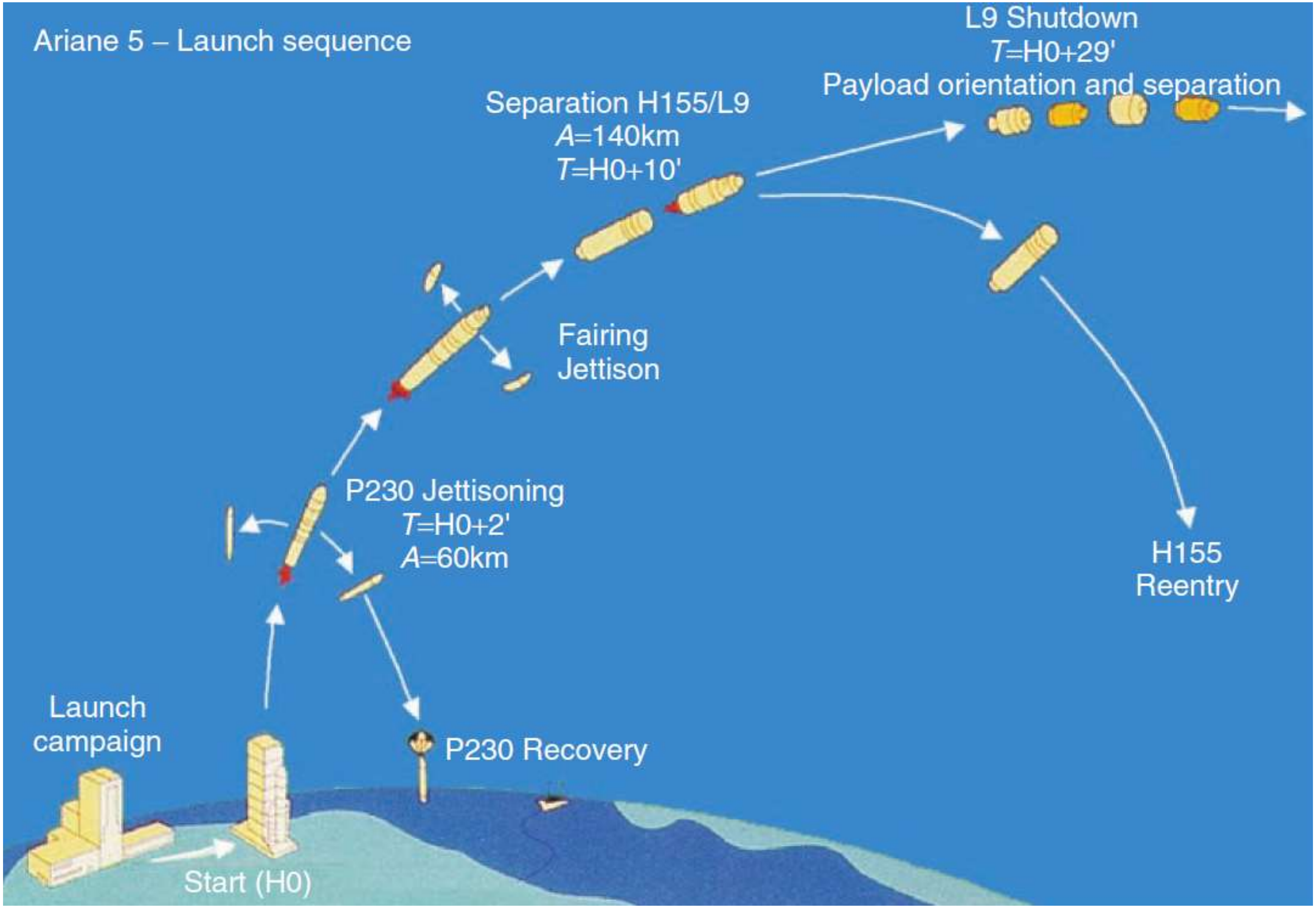
$$v_G = v_1 + v_2 + v_3 \dots$$

$$n = 1.12 \cdot v / \bar{v}$$

Ariane 5 booster (ESA)

- Combustion channel and nozzle (~3000°C)
- Burner (combustion surface): adapts the thrust curve to the trajectory

Multi-stage launch sequence (Ariane 5)



(Source: ESA)

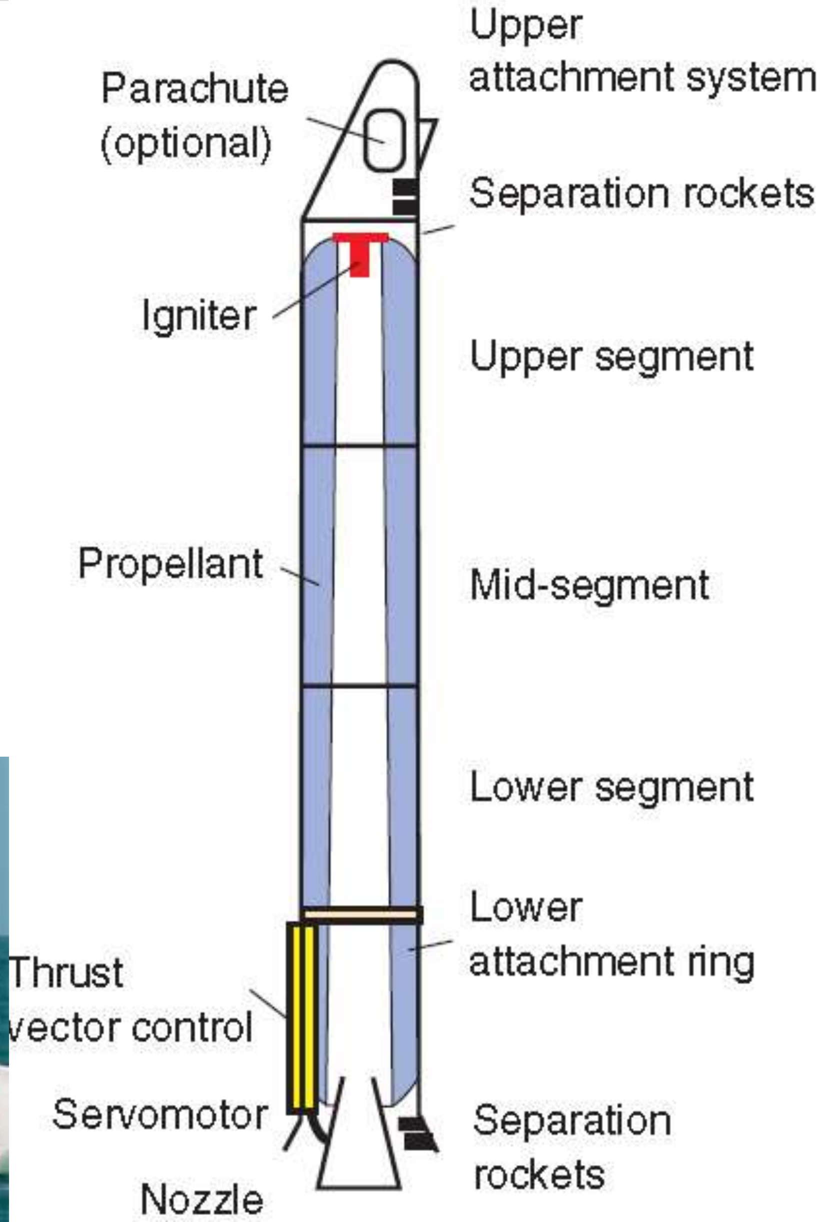
High power - Chemical propulsion

- Energy released inside a combustion chamber
- Solid, liquid or hybrid

- Propellant: mission/temperature/cycle dependent
  - H_2+O_2 (bipropellant)
  - kerosene + liquid oxygen
  - Hydrogen peroxide, H_2O_2
  - N_2H_4 (hydrazine) (monopropellant)
  - alcohol + liquid oxygen
  - solid propellants: oxidizer + propellant material
- Stages:
  - booster
  - main stage
  - upper stage
  - Apogee and Satellite Attitude Control Thrusters

The Ariane 5 booster (solid propellant)

- thrust: 6.5MN
- mass: 31+240t
  (dry mass+propellant)
- burn time: 132s
- acceleration: 2km/s
- height achieved: 69km



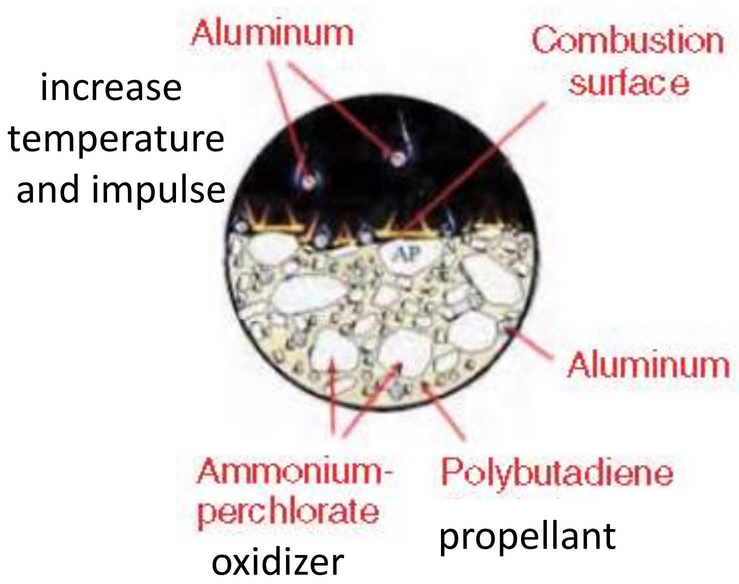
Propulsion for orbit and attitude control

- The tasks of the propulsion system:
  - Apogee injection: reach the final (e.g. circular geostationary) orbit; thrust of 400-600 N
  - Orbit control 10-22 N thrust
  - Attitude control 1-22 N
  - Breaking; corrections for long time missions

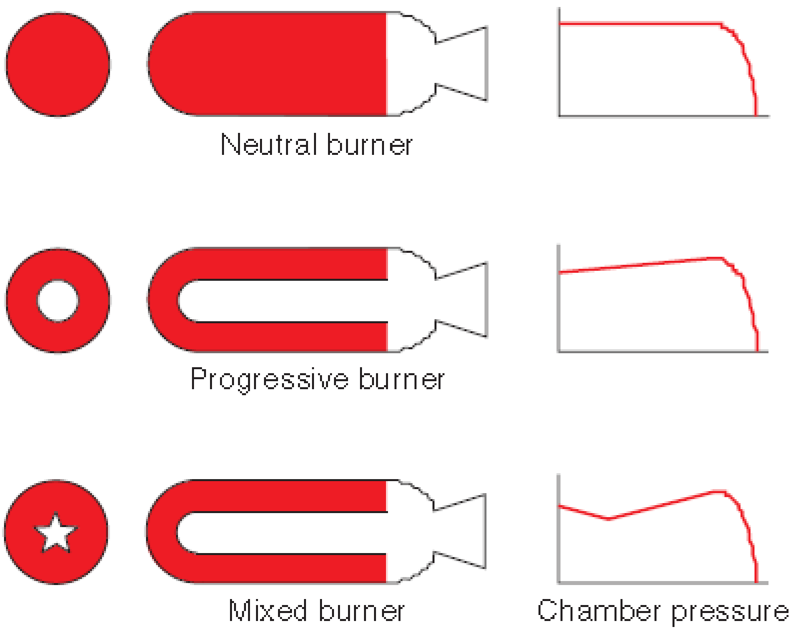
- Spacecraft stabilization influences the propulsion system design:
  - Spinning satellites (90-120 rpm): radial or axial thrusters
  - Three-axis stabilized satellites: reaction wheels + propulsion

Solid propulsion

- Limited application
  - 50-several 1000 N
  - Boosters
  - Replaced by bipropellant systems



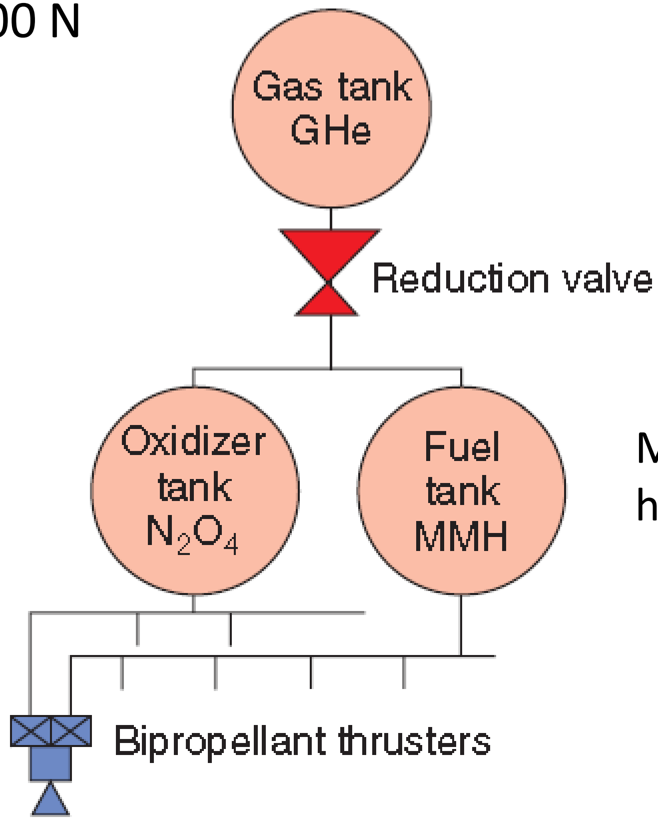
Ariane 5 booster



Bipropellant propulsion

❑More complex

- This is a “chemical” propulsion
- apogee injection
- 25 - 30% higher performance compared to monopropellant systems
- multiple tanks: fuel, oxidizer, pressure regulator
- 10-several 1000 N



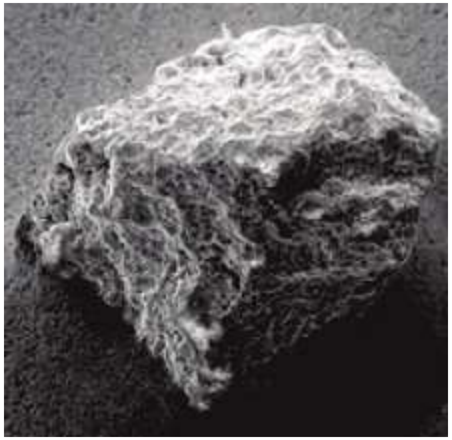
Nitrogen tetroxide

MMH=Monomethyl hydrazine

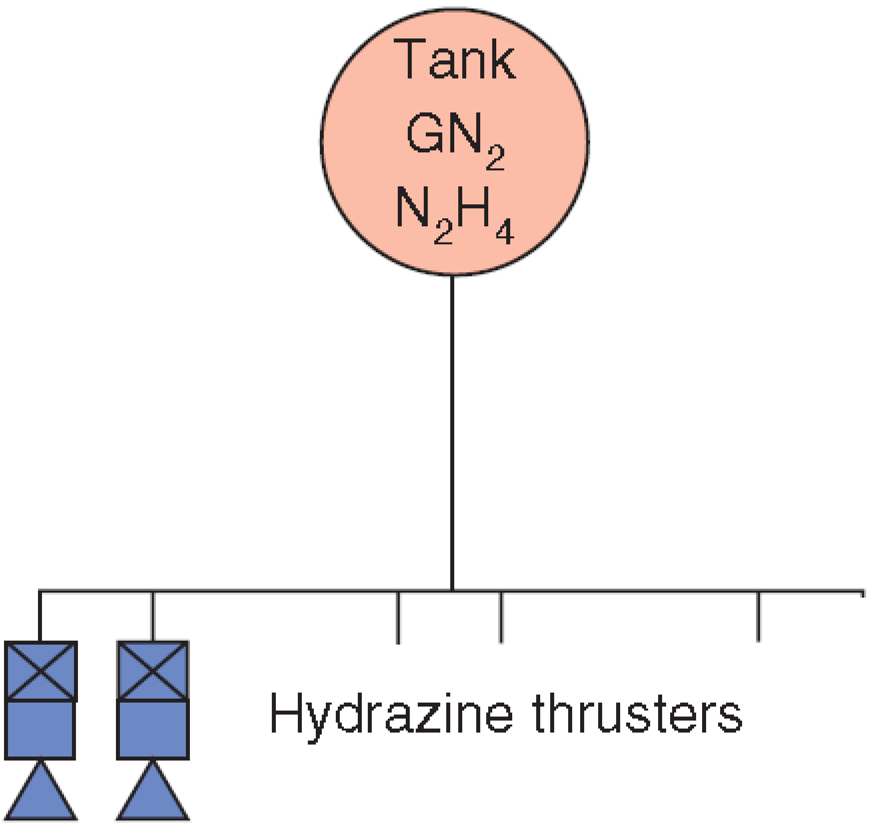
240.000 N thruster test:

Monopropellant propulsion 1.

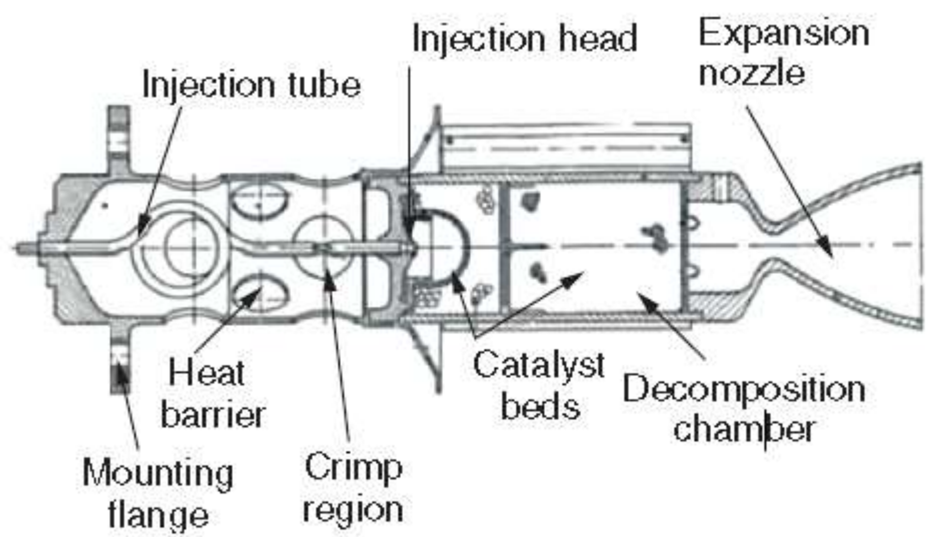
- For larger satellite mass
  - This is a "chemical" propulsion
  - Reduced propellant mass
  - Increased performance (2-3 of the cold gas system)
  - Only one propellant required: it generates hot gases
  - Hydrogen peroxide (H_2O_2) + catalyst: silver or platinum matrix
    - Non toxic, decomposes to hot water vapor
  - Hydrazine (N_2H_4) + catalyst: iridium on Al_2O_3 carrier
    - Toxic, decomposes to ammonia
  - 0.5-3000N



Monopropellant propulsion 2.



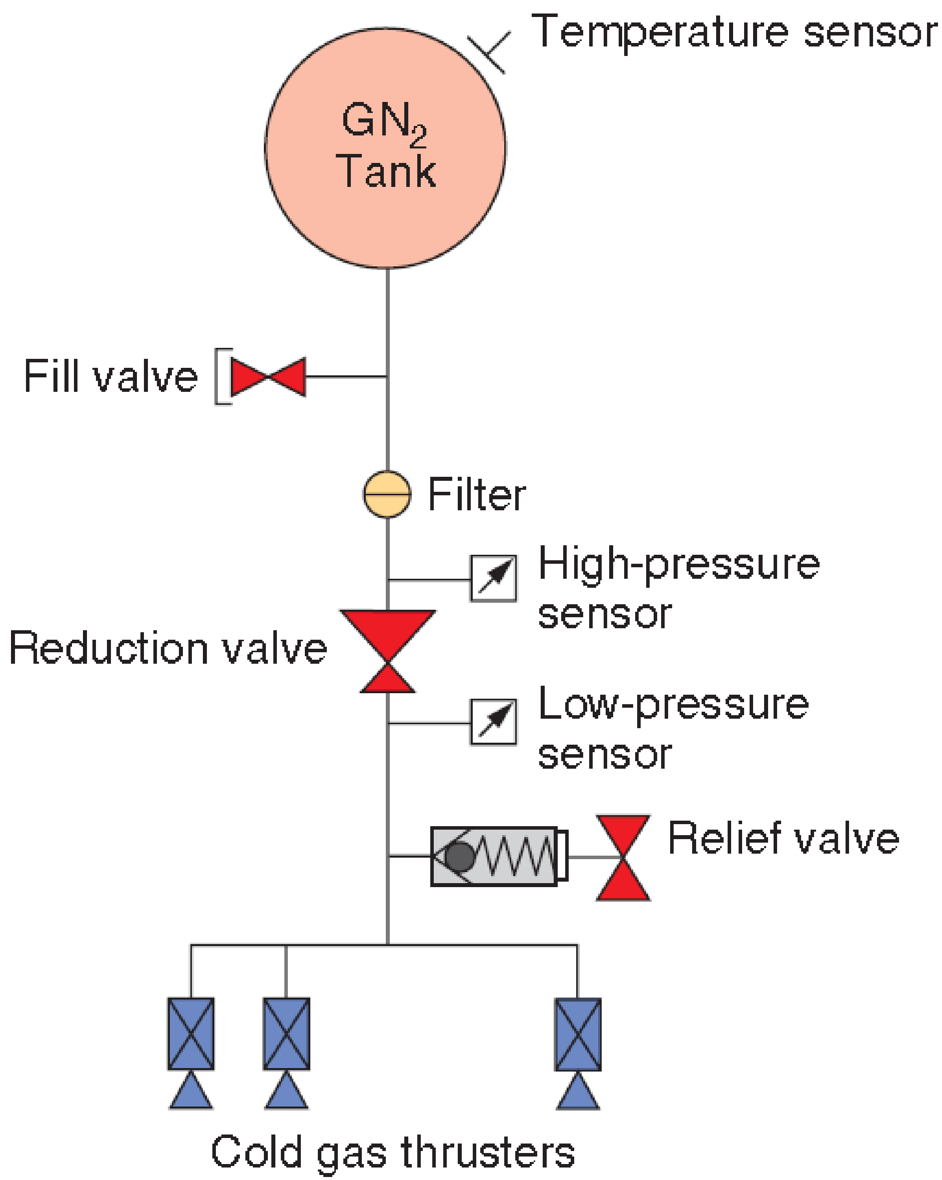
Example: Hydrogen peroxide thruster (1700N):



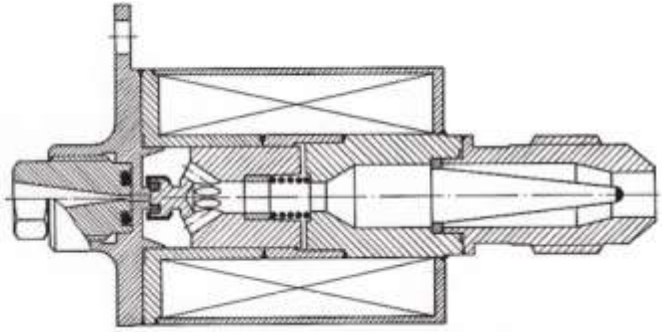
Cold gas propulsion 1.

- Simple and cost-effective
  - Nitrogen, argon (low molecular weight) or butane (microsatellites) applied
  - Regulator: pressure control
  - Valve + nozzle: pulsed or steady mode
  - 0.1-2 N: low total impulse required
  - High pointing accuracy
  - If chemical propellants prohibited (sensible sensors)

Cold gas propulsion 2.



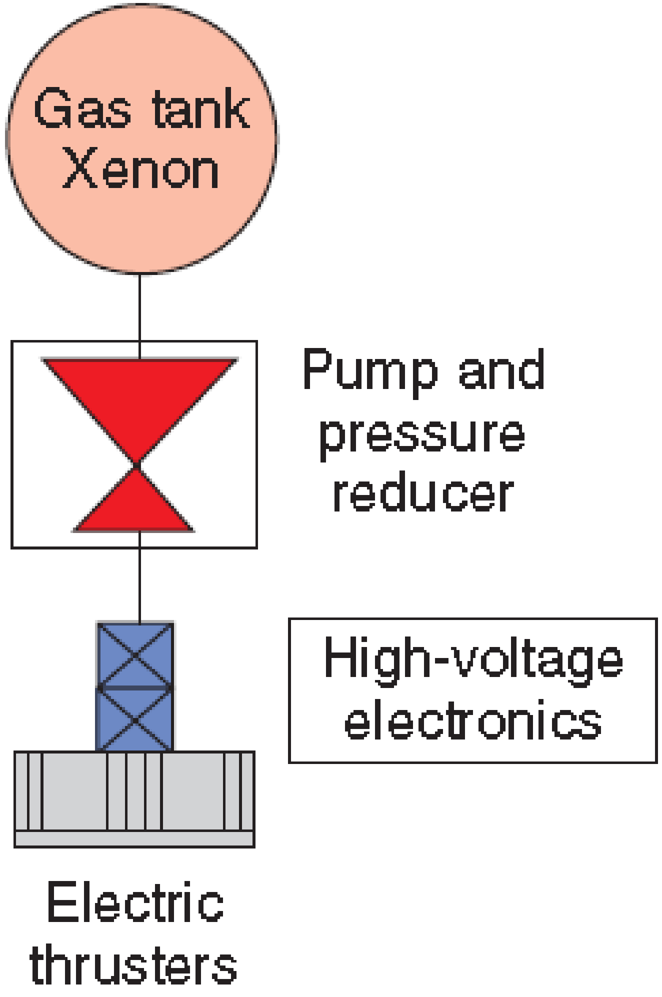
Rotate with cold gas propulsion:



Electric propulsion 1.

- Using <u>ionizable</u> gases as the propellant
  - Since the year of 2000
  - Xenon (earlier mercury); lower mass required than the chemical propulsion systems
  - Particles are accelerated to extreme velocity
  - Low thrust: millinewtons – 1 N ; long manoeuvre time
  - High performance
  - High amount of electrical energy needed
  - EMC compatibility problems due to high voltage

Electric propulsion 2.



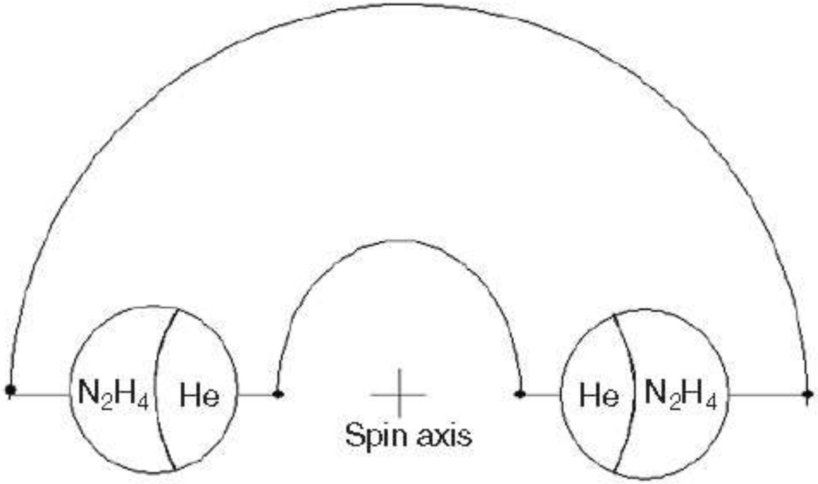
NASA's Xenon Thruster (NEXT) project

Propellant speed=40km/s

Storage of propellants

- Special tanks for high pressure (300 bar, reduced to 1-5 bar)
  - titanium
  - composite
  - Kevlar (aramid fibres: aromatic polyamides)

- Spin-stabilized satellite problem:



- Non spin-stabilized satellites: (rubber) diaphragm, surface tension

Sources:

- Gary D. Gordon, Walter L. Morgan:
  Principles of Communications Satellites
  Wiley, ISBN: 978-0-471-55796-8
- Wilfried Ley, Klaus Wittmann and Willi Hallmann (ed):
  Handbook of Space Technology
  Wiley, ISBN: 978-0-470-69739-9

Main topics / questions

- The role of the propulsion system on spacecraft and on satellite
- The role of rocket stages
- The rocket equation
- Propellant types (gas,liquid, solid / mono and bipropellant systems)
- The electric propulsion